Function, Role, and Disposition in Basic Formal Ontology

Robert Arp [*] *and Barry Smith*

National Center for Biomedical Ontology (NCBO) and New York State Center of Excellence in Bioinformatics and Life Sciences, University at Buffalo, rarp@buffalo.edu, phismith@buffalo.edu

ABSTRACT

Numerous research groups are now utilizing Basic Formal Ontology (BFO) as an upper-level framework to assist in the organization and integration of biomedical information. This paper provides elucidation of the three BFO categories of *function*, *role*, and *disposition*, and considers two proposed sub-categories of *artifactual function* and *biological function*. The motivation is to help advance the coherent treatment of functions, roles, and dispositions, to help provide the potential for more detailed classification, and to shed light on BFO's general structure and use.

1 INTRODUCTION

Many of the members of the Open Biomedical Ontologies (OBO) Foundry initiative, including the Gene Ontology, the Foundational Model of Anatomy, the Protein Ontology, and the Ontology for Biomedical Investigations (http://www.obofoundry.org/) are utilizing Basic Formal Ontology (BFO) to assist in the categorization of entities and relationships in their respective domains of research.

Fig. 1. The continuant categories of BFO.

- BFO:entity
  - continuant
    - independent continuant
      - object
      - object boundary
      - object aggregate
      - fiat object part
      - site
    - dependent continuant
      - generically dependent continuant
      - specifically dependent continuant
        - quality
        - realizable entity
          - function
          - role
          - disposition
    - spatial region
      - zero-dimensional region
      - one-dimensional region
      - two-dimensional region
      - three-dimensional region

Many individuals and groups involved in organizations such as BioPAX, Science Commons, Ontology Works, AstraZeneca, and the Computer Task Group utilize BFO as well.

Fig. 2. The occurrent categories of BFO.

- BFO:entity
  - occurrent
    - processual entity
      - process
      - process boundary
      - process aggregate
      - fiat process part
      - processual context
    - spatiotemporal region
      - scattered spatiotemporal region
      - connected spatiotemporal region
        - spatiotemporal instant
        - spatiotemporal interval
    - temporal region
      - scattered temporal region
      - connected temporal region
        - temporal instant
        - temporal interval

Versions of BFO in OBO, OWL and first-order logic formats are maintained by Holger Stenzhorn at http://www.ifomis.org/bfo. Definitions and other content taken from there have been modified to provide additional clarity of exposition.

BFO is an upper-level ontology developed to support integration of data obtained through scientific research. It is deliberately designed to be very small, in order that is should be able to represent in consistent fashion the upper-level categories common to domain ontologies developed by scientists in different domains and at different levels of granularity. BFO adopts a view of reality as comprising (1) *continuants*, entities that continue or persist through time, such as objects, qualities, and functions, and (2) *occurrents*, the events or happenings in which continuants participate. The subtypes of continuant and occurrent represented in BFO are presented in Figures 1 and 2 (Grenon and Smith, 2004; Smith and Grenon, 2004; http://www.ifomis.uni-saarland.de/bfo/).

[*] To whom correspondence should be addressed.

2 FUNCTION, ROLE, AND DISPOSITION

Use of the term 'function' is common in descriptions of molecular and cellular processes, as in assertions such as:

- the function of the kidney of *Mus musculus* is to filter out waste and water which become urine,
- *Arabidopsis thaliana* has a multifunctional protein
- *there are several fo*lD bifunctional proteins in *Campylobacter jejuni*.

Functions thus play a central role in the Gene Ontology (http://www.geneontology.org/).

What, however, of the non-biological functions of artifacts such as screwdrivers, microplates, or pycnometers? Are there both designed (artifactual) and natural (biological) functions, representing distinct subtypes of the more general category of BFO:function?

A related issue is that of the use of the terms 'function' and 'role'. These are distinguished by BFO as representing two distinct categories (Figure 1), but outside BFO circles they are often used interchangeably, as when function is defined as 'the *role* that a structure plays in the processes of a living thing'. Analogous difficulties arise with regard to the terms 'disposition' and 'tendency', as in: 'blood has the tendency or disposition to coagulate', 'a hemophiliac has the disposition or tendency to bleed an abnormally large amount of blood', and 'that patient has suicidal dispositions or tendencies'.

In this paper, we attempt to elucidate the categories of *function*, *role*, and *disposition* in BFO. We also describe two sub-type categories of function, the *artifactual* and the *biological*, and provide definitions for each.

Within the context of BFO, one should correctly state:

- the (or a) *function* of the heart is to pump blood
- the *role* of the surrogate is to stand in for the patient
- blood has the *disposition* to coagulate
- that patient has suicidal *tendencies*

To see why this is so, we need first to consider BFO's more general approach to classification.

In BFO, all entities are divided into *continuants* and *occurrents*; continuants in turn are divided into *independent* and *dependent*. Independent continuants are things (the objects we see around us every day) in which dependent continuants—such as qualities, functions, roles, dispositions—can inhere.

Dependent continuants stand to their bearers in the relation of existential dependence: in order for them to exist, some other (independent) entity must exist. For example, instances of qualities such as *round* and *red* are dependent continuants in that they cannot exist without being qualities of some independent continuant such as a ball or a clown's nose. So too, functions, roles, and dispositions exist only insofar as they are functions, roles, and dispositions of some (one or more) independent continuant. The function of my heart is an instance of the BFO type *function*, and so also is the function of your heart.

One major subcategory of dependent continuants in BFO is that of *realizable entity*. Realizable entities are defined by the fact that they can be realized (manifested, actualized, executed) in occurrents of corresponding sorts. Examples of realizable entity types include: the function of the liver to store glycogen, the role of being a doctor, the disposition of metal to conduct electricity.

Realizable entities are entities of a type whose instances are typically such that in the course of their existence they contain periods of actualization, when they are manifested through processes in which their bearers participate. They may also exhibit periods of dormancy where they exist by inhering in their bearers, but are not manifested, as for example, in the case of certain diseases. Some realizables, such as the function of a sperm to penetrate an ovum, may be such that they can be manifested only once in their lifetime; or, as again in the case of sperm, they are realized only in very rare cases.

We are now in a position where we can define *function*, *role*, and *disposition*.

2.1 Function

A *function* f is

(1) a realizable dependent continuant.

Thus,

(2) it has a bearer, which is an independent continuant, and

(3) it is of a type instances of which typically have realizations; each realization is
   a. a process in which the bearer is participant
   b. that occurs in virtue of the bearer's physical make-up,
   c. and this physical make-up in something which that bearer possesses because of how it came into being.

Examples include: the function of a birth canal to enable transport and the function of a hammer to drive in nails. The process under a. may be specified further as an end-directed activity, by which we mean in the biological case something like: an activity that helps to realize the characteristic physiology and life pattern for an organism of the relevant type. Each function has a bearer with a physical structure which, in the biological case, the bearer has naturally evolved to have (as in a hypothalamus secreting hormones) or, in the artifact case, the bearer has been constructed to have (as in an Erlenmeyer flask designed to hold liquid) (Ariew and Perlman, 2002).

It is not accidental or arbitrary that a given eye has the function to see or that a given screwdriver have been designed and constructed with the function: to fasten screws. Rather, these functions are integral to these entities in virtue

of the fact that the latter have evolved or been constructed to have a corresponding physical structure.

If a continuant has a function, then it is built to exercise this function reliably on the basis of this physical structure. But again: a function is not in every case exercised or manifested. Its bearer may be broken; it may never be in the right kind of context. Hence, when we say that a given structure is designed in such a way as to bring about a certain end reliably, then this reliability presupposes the fulfillment of certain conditions, for example of an environmental sort.

On the level of instances, this can be stated as: if f is the function of c, then (in normal circumstances), c exercises f.

On the level of universals, as: if F is the function universal exemplified by instances of the independent continuant universal C, then (in normal circumstances) instances of C participate in process instances which are realizations of F. The implications of this analysis for the treatment of functions in the Gene Ontology are outlined in Hill, Smith, McAndrews-Hill, and Blake (2008).

2.2 Role

In contrast to function, *role* is a realizable entity whose manifestation brings about some result or end that is not typical of its bearer in virtue of the latter's physical structure. Rather, the role is *played* by an instance of the corresponding kind of continuant entity because this entity is in some special natural, social, or institutional set of circumstances (http://www.ifomis.org/bfo).

Examples include: the role of a chemical compound to serve as analyte in an experiment, the role of penicillin in the treatment of a disease, the role of bacteria in causing infection, the role of a person as student or surgeon.

What is crucial for understanding a role—as distinct from a function—is that it is a realizable entity that an independent continuant can take on, but that it is not a reflection of the in-built physical structure of that independent continuant. Certain strains of *Escherichia coli* bacteria have the role of pathogen when introduced into the gut of an animal, but they do not have this role when merely floating around in a pool of water. A heart has the function of pumping blood; but in certain circumstances that same heart can play the role of dinner for the lion.

Roles are optional, and they often involve social ascription. This is why a person can play the role of being a lawyer or a surrogate to a patient, but it is not necessary for persons that they be lawyers or surrogates.

So, when researchers are considering whether some realizable entity is a function or a role, the question to ask is this: Is the realizable entity such that its typical manifestations are based upon its physical structure? If so, then it is a function. Or, is the realizable entity such that its typical manifestation is a reflection of surrounding circumstances, especially those involving social ascription, which are optional? If so, then it is a role.

From this perspective, it is incorrect to make assertions such as:

- the *role* of the heart is to pump blood;
- driving nails is a *role* that this hammer fulfills;
- the *function* of the surrogate is to stand in for the patient;
- the *function* of James is to serve as my servant.

2.3 Disposition versus Tendency

It is common to find researchers making claims like: 'water has the disposition to rise in a tube', 'Carbon-10 has a disposition to decay to Boron-10', and 'the cell wall is disposed to filter chemicals in endocitosis and exocitosis.' A *disposition* is a realizable dependent continuant that typically causes a specific process in the object in which it inheres when the object is introduced into certain specific circumstances. In addition, these processes occur as a result of the object's physical structure (Jansen, 2007).

A disposition invariably leads to a certain result given certain circumstances. Consider: the disposition of a car windshield to break if struck with a sledgehammer moving at 100 feet per second; the disposition of a cell to become diploid following mitosis; the disposition of a magnet to produce an electrical field.

Contrasted with a disposition is a *tendency*, which is a realizable dependent continuant that potentially (not invariably or definitely) causes a specific process in the object in which it inheres when the object is introduced into certain specific circumstances as a result of the object's physical structure property.

Examples include: the tendency on the part of a hemophiliac to bleed an abnormally large amounts of blood and the tendency on the part of a person who smokes two packs of cigarettes a day throughout adulthood to die of a disease at a below average age. A patient may have a tendency, and not a disposition, to commit suicide; while a crystal vase has a disposition, and not a tendency, to break when it hits the ground after being dropped from a tall building. We are referring to tendencies when we refer to genetic and other *risk factors* for specific diseases.

3 TWO SUB-CATEGORIES OF FUNCTION

It is possible that BFO has failed to recognize categories or sub-categories of entities existing in reality. The ontology is, however, developed on the basis of a principle of scientific fallibilism (Grenon and Smith, 2004). Thus, it is possible that future research in ontology or in the natural sciences will reveal the need for an expansion or restructuring of the categories that BFO recognizes.

In its present form, BFO categories are those included in the taxonomic hierarchy illustrated in Figures 1 and 2 above. However, we are exploring the possibility of introducing two sub-categories under function, namely *artifac-*

tual function and *biological function*, as illustrated in Figure 3.

We are also exploring the question of whether to include tendency as a further sub-category within the ontology.

Fig. 3. Two proposed sub-categories of function in BFO.

BFO:realizable entity
- function
  - artifactual function
  - biological function
- role
- disposition

3.1 Artifactual Function

An *artifactual function* is a function which inheres in an independent continuant that exists, and has the physical structure which it has, because it has been designed and made intentionally (typically by one or more human beings) to function in a certain way and does indeed reliably function in this way (Lind, 1994; Dipert, 1993).

Examples include: the function of a pycnometer to hold liquid, the function of a fan to circulate air, and the function of a Bunsen burner to produce a flame.

3.2 Biological Function

A *biological function* is a function which inheres in an independent continuant that is (i) part of an organism and (ii) exists and has the physical structure it has as a result of the coordinated expression of that organism's structural genes (Rosse and Mejino, 2003). The manifestations of a function of this sort form part of the life of the organism.

Examples include: the function of a mitochondrion in the production of ATP and the function of the wax-producing mirror gland of the worker honey bee to produce beeswax.

The manifestations of biological functions are not in every case beneficial to the survival of the corresponding organism. (Consider the case of organisms that die when they reproduce, like *Arabis laevigata* and *Octopus lutens*.) Rather, they are (in typical environments) such as to contribute to the realization by an organism of a life that is typical or characteristic for an organism of its kind.

It is an open question whether the dichotomy between biological and artifactual function should or should not be included as an addition to BFO, or reflected rather in the creation of two new domain ontologies of artifactual and of biological functions. The latter has already been proposed as a complement to the GO's molecular function and biological process ontologies.

ACKNOWLEDGEMENTS

We wish to thank Andrew Spear for helpful comments. This work is funded by the United States National Institutes of Health (NIH) through the NIH Roadmap for Medical Research, Grant 1 U54 HG004028.

REFERENCES

Allen, C., Bekoff, M., and Lauder, G., eds. (1998) *Nature's Purposes: Analyses of Function and Design in Biology*. MIT Press, Cambridge.

Ariew, A. and Perlman, M. (2002) Introduction. In A. Ariew, R. Cummins, and M. Perlman, eds., *Functions: New Essays in the Philosophy of Psychology and Biology* (pp. 1–7). Oxford University Press, New York.

Arp, R. (2006) Evolution and two popular proposals for the definition of function. *Journal for General Philosophy of Science*, **37**, 2–12.

Dipert, R. (1993) *Artifacts, Art Works, and Agency*. Temple University Press, Philadelphia.

Grenon, P. and Smith, B. (2004) SNAP and SPAN: Towards dynamic spatial ontology. *Spatial Cognition and Computation*, **4**, 99–104.

Hill, D., Smith, B., McAndrews-Hill, M., and Blake, J. (2008) Gene Ontology annotations: What they mean and where they come from. *BMC Bioinformatics*, **9**, S2.

Hunter, L. (2009) *An Introduction to Molecular Biology for Computer Scientists*. MIT Press, Cambridge, MA. In preparation.

Jansen, L. (2007) Tendencies and other realizables in medical information sciences. Available at: http://ontology.buffalo.edu/bfo/Tendencies.pdf.

Lind, M. (1994) Modeling goals and functions of complex industrial plants. *Applied Artificial Intelligence*, **8**, 259–283.

Perlman, M. (2004) The modern philosophical resurrection of teleology. *The Monist*, **87**, 3–51.

Rosse, C. and Mejino, J. (2003) A reference ontology for bioinformatics: The Foundational Model of Anatomy. *Journal of Biomedical Informatics*, **36**, 478–500.

Smith, B. and Grenon, P. (2004) The cornucopia of formal-ontological relations. *Dialectica*, **58**, 279–296.

Smith, B., Kusnierczyk, W., Schober, D., and Ceusters, W. (2006) Towards a reference terminology for ontology research and development in the biomedical domain. *Proceedings of KR-MED*, **1**, 1–10.

Smith et al. (2007) The OBO Foundry: Coordinated evolution of ontologies to support biomedical data integration. *Nature Biotechnology*, **25**, 1251–1255.